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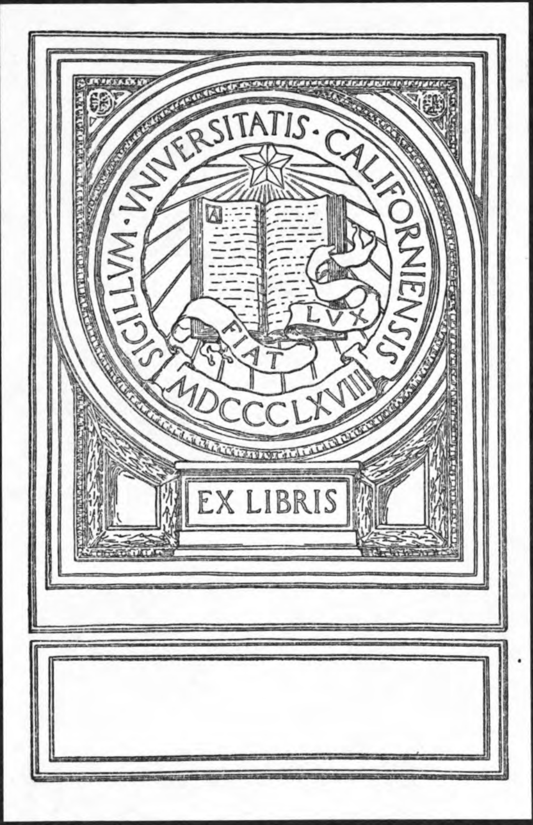
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AUDIOMETRIC MEASUREMENTS AND THEIR USES

BY

HARVEY FLETCHER

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A DISCUSSION OF THE PRACTICAL USES
OF AUDITION MEASUREMENTS MADE WITH AUDIOMETERS

REPRINT OF PAPER
Published in
TRANSACTIONS OF THE
COLLEGE OF PHYSICIANS OF PHILADELPHIA
1923
Presented before
SECTION ON OTOLOGY AND LARYNGOLOGY
COLLEGE OF PHYSICIANS OF PHILADELPHIA
PHILADELPHIA, PA. APRIL, 1923

Printed in the
United States of America

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AUDIOMETRIC MEASUREMENTS AND THEIR USES

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(*Notes on a Talk.*)

THE talk comprised a discussion of the problem of making measurements of the degree of hearing and the practical applications of such measurements. It was illustrated by experiments with audiometers which were designed by the Western Electric Company in coöperation with Dr. E. P. Fowler.

Three types of audiometers were described and referred to as Types I, II and III. In each of these types the tone is delivered to the ear by means of a special telephone receiver. For the first two types the electrical generator supplying the current to this telephone receiver is of the audion bulb type. The various frequencies are obtained by varying the constants of the electrical circuit. In the third type of audiometer the generator is of the vibrating reed type. It gives only a compound tone of variable intensity. An analysis of this tone shows that it has frequency components throughout the important range of speech frequencies. The scale is arranged so that when the intensity dial is varied, until the threshold of hearing is reached, its reading gives the per cent hearing for speech.

The first type of audiometer was designed primarily for use in hospitals, medical schools and for highly specialized workers. It has a frequency range divided into twenty steps from 64[1] to 16,384 double vibrations per second, and an intensity range of approximately 100,000,000,000 divided into twenty-eight steps.

In order to demonstrate the performance of this audiometer the head receivers which are ordinarily used were replaced by a loud-speaking receiver so that all in the room could hear the

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[1] In a redesigned audiometer this range has been extended to thirty-two vibrations per second.

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various tones that the instrument produced. When high frequencies are produced in an ordinary room standing waves occur, due to the reflection from the walls. As a consequence of this it is extremely difficult to avoid errors in measuring hearing by the usual methods. Those in the audience verified the fact that moving the head through only small distances was sufficient to change the loudness of the sound from almost zero to very high values. This source of error is avoided when the sound is delivered directly to the ear by a telephone receiver.

The scales on the audiometers are arranged so that equal steps produce equal loudness changes as perceived by the ear If the intensity dial is rotated uniformly the tone dies away in the same manner as that from a vibrating tuning-fork held in the air. The great advantage of the audiometer over tuning-forks is that the tone can be held at a constant intensity at any desired value, whereas with the tuning-fork the intensity continually decreases. Also the intensity of the sound from the audiometer is definitely known in absolute units, so that if desired the actual amplitude of the sound wave in the auditory meatus can be calculated.

Type II audiometer is similar in performance to Type I, but is limited in its frequency and intensity range. Its frequency range is from 64 to 8192 double vibrations per second, being divided into eight steps, each step corresponding to an octave on a musical scale. Its intensity range is approximately 10,000-000,000.

As indicated above, the Type III audiometer is arranged to read directly the average per cent hearing. The zero hearing-point is taken as the average intensity where one feels the sound wave. The 100 per cent hearing-point is taken as the average threshold intensity for people who are known to have normal hearing. The first intensity-point corresponds to that produced when one talks very loud directly into the ear. The range of intensities between these two points is divided into one hundred equal loudness steps. This type of audiometer was designed to fulfil the demand for a quick test and is particularly adapted for use in the army and navy, public schools and large industrial concerns.

By means of an audiometer similar to those described, an accurate measurement was made of the range of hearing in intensity and frequency for persons having normal hearing. The final results of such measurements are shown in Fig. 1. The abscissæ represent frequencies which are expressed both directly and logarithmically along the axis; the ordinates represent intensities and are expressed both as amplitudes of pressure variation (of the sound in the auditory meatus) and as loudnesses in loudness units.[1] The lower curve gives the threshold of hearing; the upper curve the threshold of feeling. Their intersection points are at the upper and lower limits of audibility.[2] The area enclosed between these two curves has been named "the auditory sensation

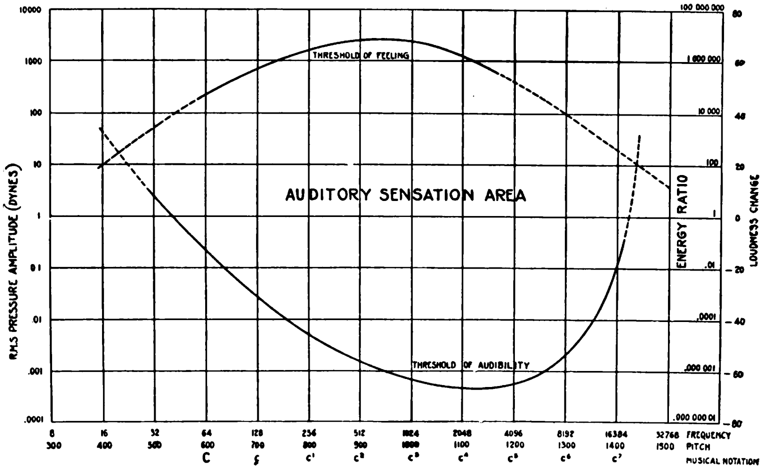

FIG. 1

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[1] For discussion of loudness units, see paper given before the Franklin Institute March 29, 1923, published in the Journal of that Institute.

[2] For methods of determining these curves, see papers by H. Fletcher and R. L. Wegel in the Physical Review, June, 1922, No. 6, xix, and Proceedings of the National Academy of Science, July, 1922, No. 7, viii.

area." Each point in it corresponds to a particular tone having a definite frequency and intensity, which can be sensed by the average ear. The pitch and loudness scales are so chosen that the numerical value of the area of any portion of this auditory sensation area is approximately equal to the number of pure tones in this region that are perceptibly different.

Typical audiograms or threshold-of-audibility curves for six types of deafness are shown in Fig. 2. The threshold of hearing-curve is represented in its relation to the normal auditory-sensation area. The fraction of the normal auditory area above the abnormal threshold curve is taken as the per cent hearing, since it represents approximately the number of pure tones available for the deaf man's use compared with those available for the average person of normal hearing. The Type III audiometer is designed to give very quickly an approximate value of the per cent of hearing as thus defined.

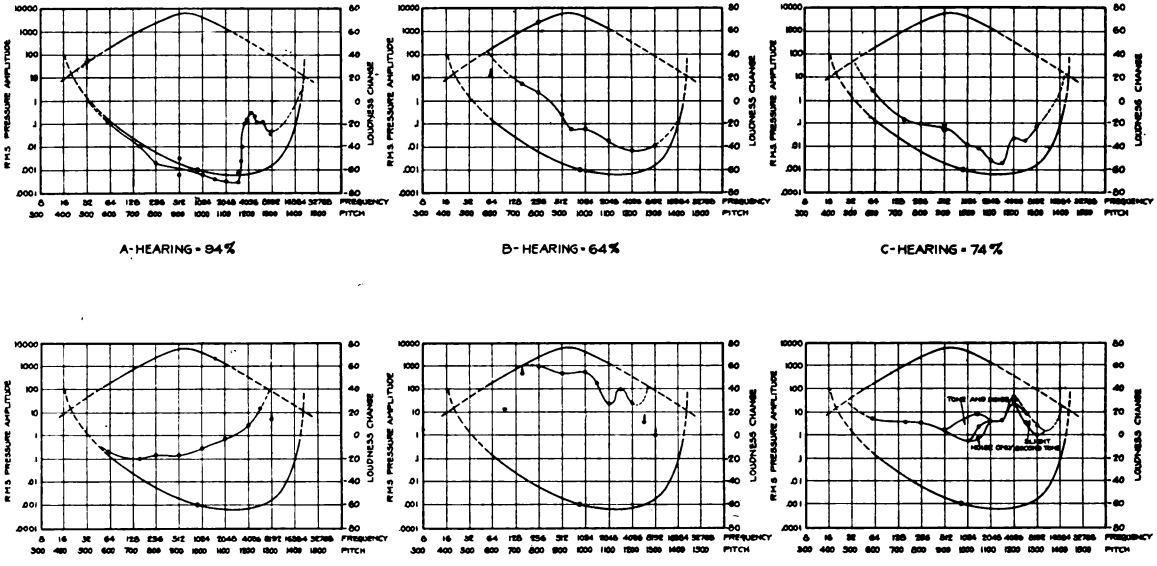
For clinical purposes one is usually more interested in departures from the normal than in absolute values. In Fig. 3 the same audiograms are shown as those in Fig. 2, but they are plotted as departures from the normal, *e.g.*, we plot the distance from the normal to the abnormal curve measured in loudness units as a function of frequency. The Type II audiometer is designed so that such curves can be plotted directly from the scale readings on the intensity dial.

There are three principal uses for audiometers, namely:

1. For making physical examinations of candidates for schools, for the army and navy, or for large industrial concerns, etc.

2. For diagnostic purposes.

3. For obtaining data for prescribing aids to the hearing. In school it is very desirable to separate those with abnormal hearing from the other children, so that they may receive special instruction. Also, the pupils in this segregated group should again be divided into probably three or four groups according to their degree of hearing. This can be done very quickly with the Type III audiometer.



A-HEARING = 94%

B-HEARING = 64%

C-HEARING = 74%

D-HEARING = 58%

E-HEARING = 12%

F-HEARING = 40%

FIG. 2.—Audeograms for Typical Cases of Deafness.

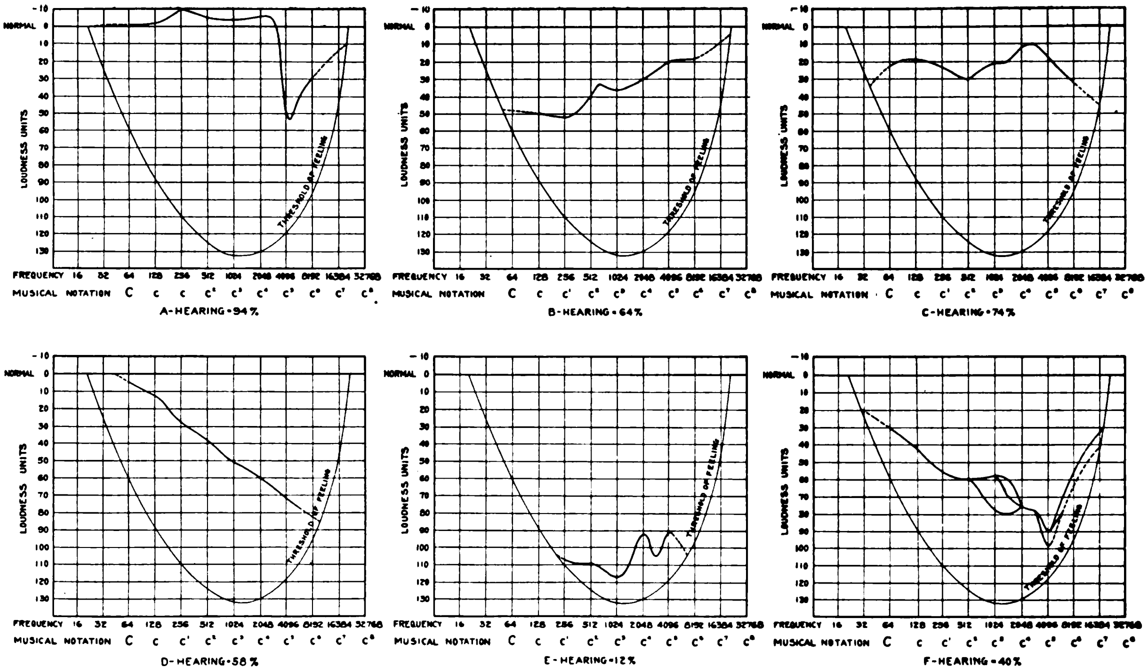


FIG. 3.—Audeograms for Typical Cases of Deafness.

The usefulness of audiometers in the army and navy is very evident. They will be extensively used not only for measurements on applicants but for periodic measurements of those in the service.

The full significance of audiometric measurements for diagnostic purposes is not at present understood. A full understanding can come only after the ear specialists have had considerable experience with these instruments. However, it seems reasonable to expect that when accurate audiograms for each known case are kept on file, information will soon accumulate from which some important generalizations can be made. Recent discussions of this phase of the work have been made by Dean and Bunch,[1] Wilson and Minton[2] and Fowler and Wegel.[3]

The third use mentioned has received little attention by ear specialists. This is due principally to two facts, namely: (1) That the physical properties, expressed in definite numerical terms, of the existing types of aids to the hearing are not generally known; (2) the existing audiometric measurements are not sufficiently standardized to enable an otologist to give accurate numerical figures for the degree of deafness. There are a number of factors which must be taken into account before one can tell accurately whether any of the existing sets will materially aid the hearing, but a few general principles will be set down here to serve as a beginning.

The proper volume of speech for any case of deafness can be determined rather accurately, but it will require considerable experience with the various types of deafness before one can expect great proficiency in prescribing deaf sets. For the purpose of determining the proper volume of speech necessary for good hearing a set of curves showing the relation between the interpretation and the volume or loudness of speech was determined. The quantitative measure for this interpretation is taken as the per cent of received syllables which are properly understood and is called "the articulation." Such a set of curves is shown in Fig. 4. These curves were determined by a large number of tests[1] with persons of normal hearing and from our limited experience with people having abnormal hearing. The curve marked "100 per cent hearing" shows the articulation for persons of normal hearing as a function of the "loudness" or "volume" of speech, which is plotted along the axis of abscissæ and with the zero at the loudness corresponding to a speaker talking directly into the ear with normal conversational volume. The intensity corresponding to this standard loudness is called "the initial speech intensity." It is seen that this curve intersects the axis of abscissæ at 100. This shows that speech can be diminished 100 loudness units below its initial intensity before

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[1] Audiometer in the Otological Clinic, Am. Otol. Soc. Proc., 1920, Part II, vol. xv: Laryngoscope, August, 1919.

[2] Proc. Inst. Med. of Chicago, 1921, pp. 157–171.

[3] Audiometric Methods and Their Applications, Trans. Am. Laryn., Rhinol. and Otol. Soc., 1922.

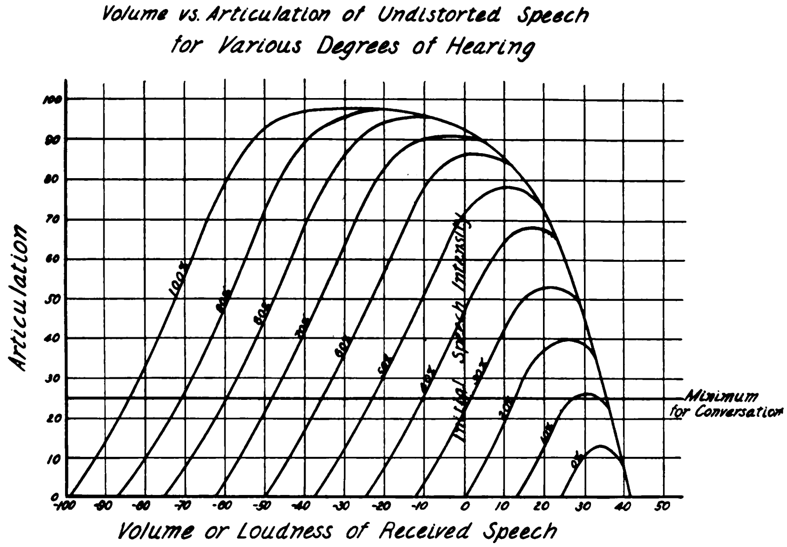

Fig. 4

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[1] Fletcher, H.: The Nature of Speech and Its Interpretation, Franklin Institute, June, 1922.

it becomes inaudible. This number of loudness units corresponds to an intensity ratio of 10^{10} or 10,000,000,000.[1]

The best loudness for interpreting speech is 30 units below the standard loudness as defined above. At 60 units below this standard one still obtains good interpretation if his hearing is normal and if there is no noise present. At 90 units below this intensity one can scarcely hear anything but the loud vowel sounds. The falling off of the interpretation at high volumes is partly due to the distortion produced by the ear on account of the large number of subjective tones which are introduced at these high intensities. The introduction of these subjective tones makes it difficult to sense the speech sounds in their proper proportions.

The other curves in this figure give similar relations for persons having various degrees of hearing. In these curves the threshold of audibility for speech, which is also the zero articulation point, is shifted toward the standard loudness or zero point on the axis of abscissæ. This shifting is accompanied by an increased ear distortion. The amount of this ear distortion varies greatly with the type of deafness. These curves give the probable values of the articulation for various degrees of deafness of the kind in which there is not greater distortion than in the normal ear.

To find the articulation on the per cent of speech syllables which are correctly interpreted for a deaf person having more ear distortion than normal, the values from these curves must be multiplied by a factor which we will call "the deafness distortion factor." This factor is dependent upon the type of deafness and can be determined experimentally for each case. This is done by pronouncing directly into the ear (lips less than one-half inch away from the ear) a list of monosyllabic words and finding how many the patient interprets correctly. In this test care should be taken not to raise the voice above the normal conversational volume. From the set of curves in Fig. 4, read the articulation corresponding to the initial speech intensity on the particular curve corresponding to the per cent of hearing obtained from the audiometric measurements. The ear-distortion factor is then found by dividing the per cent of words interpreted correctly under the conditions described above by the value of this particular ordinate. For cases having more than 50 per cent hearing it is more convenient to make the articulation test with the mouth one foot away from the ear. When made in this way the ordinate at -23 instead of at 0 should be used in obtaining the ear-distortion factor.

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[1] Fletcher, H.: Physical Measurements of Audition and Their Bearing Upon the Theory of Hearing, Journal of Franklin Institute, July, 1923.

With this data available it is possible to determine approximately the articulation that will be obtained by the patient at any volume of received speech. For example, let us assume that the audiometer tests indicate that the patient has 40 per cent hearing and the articulation measurements at the standard loudness show 30 words out of 100 are correctly interpreted. The ordinate of the curve at abscissa zero for 40 per cent hearing is seen to be 47 per cent. Then the ear distortion factor is $\frac{30}{47}$, or 0.64. By talking very loudly and directly into the patient's ear a loudness of approximately 10 units higher than standard can be attained. With this loudness the 40 per cent hearing curve gives 70 per cent articulation which when multiplied by 0.64 gives 45 per cent. This then is the approximate articulation that the patient would obtain under such conditions. For certain types of deafness this factor is so small that no amount of amplification of speech would enable the patient to interpret enough syllables to understand satisfactorily. However, it must be remembered that a low distortion factor may be due to a lack of education because the speech sounds are heard so infrequently. With a deaf set giving the proper volume this distortion factor should increase very materially with practice. From a very limited experience we have drawn the line at 25 per cent articulation as representing the least syllable articulation that one can have and still be able to carry on a conversation.

In Fig. 5 curves are shown which give the volume efficiency of typical hearing aids now on the market. The ordinate gives the loudness of the speech at the ear measured on the usual scale when the speaker is at the distance from the transmitter (or in the case of the curve marked "average speech unamplified" the distance from the ear) given by the abscissa. This curve represents the effects in a room 25 x 18 feet. From the curves in Figs. 4 and 5 it will be seen that for the case of deafness considered above namely, 40 per cent hearing, the patient could not hear speech at distances greater than a foot and a half from the ear if it were spoken at the average conversational volume.

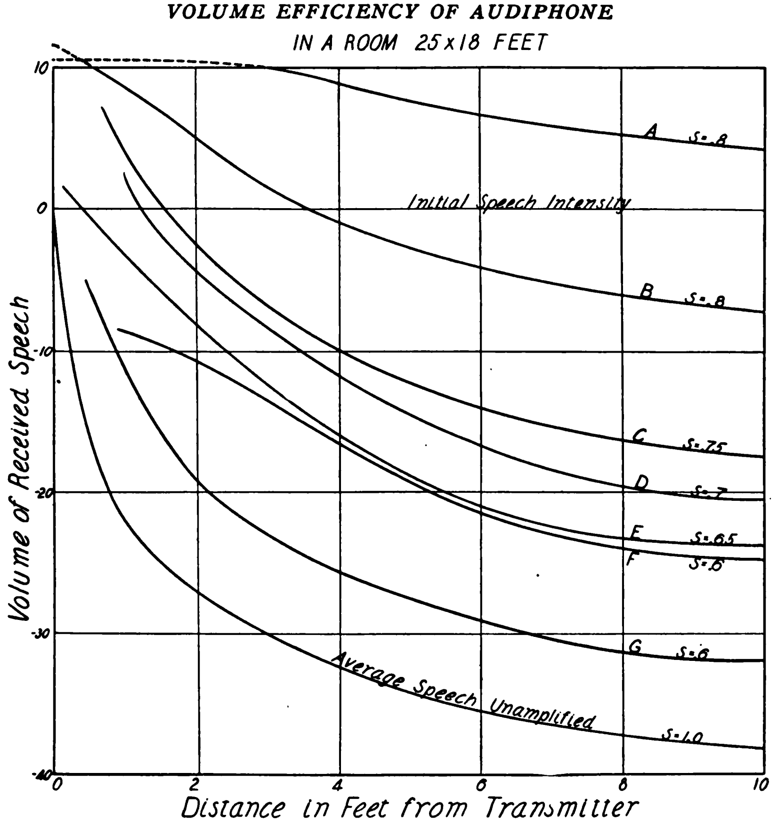

Fig. 5

These sets of curves enable one to prescribe the proper type of set from a volume standpoint. For example, consider the case just mentioned. For an ear distortion of 0.64 and with a deaf set, which gives perfect reproduction, the volume which must be delivered in order to keep the per cent articulation above 25 must be −6 units. The ordinate corresponding to this volume in Fig. 4 is 39, which when multiplied by 0.64 gives 25 per cent. Deaf set "C" would give the required volume for distances less than two feet, deaf set "B" would be satisfactory for about five feet, and deaf set "A" would enable the patient to hear the speaker anywhere in a room even larger than that in which these tests were made.

These conclusions are correct only if the deaf set gives perfect reproduction for speech. Of course, this is far from being the case. Another factor must be introduced which we will call "the deaf-set distortion factor." Such factors are given on the curves in Fig. 4 and designated by the letter "S." This factor has been determined for the case when the speaker is three feet from the transmitter. It was obtained by finding the articulation of speech delivered by these sets to one having normal hearing. For smaller distances this factor is usually greater and for larger distances less than that for the three-feet distance, the amount depending on the acoustics of the room. Some account can be taken of these acoustic effects, but I do not desire to enter into a detailed discussion of that phase of the subject here.

For the case of deafness considered above the set "B" used at three feet distance would then give an articulation of 55 per cent × 0.64 × 0.8 = 28 per cent. The set would then be sufficiently satisfactory to carry on a conversation at this distance, although with some difficulty. If the deaf set "A" were used the articulation would be 70 × 0.64 × 0.8 = 36 per cent at three feet distance, which indicates a satisfactory interpretation of speech. Even at a distance as great as ten feet the articulation would be satisfactory.

This method of combining the ear distortion factor and the deaf-set distortion factor, that is by multiplying one by the other, gives results which agree approximately with those observed with persons having average types of deafness. However, it is expected that further research will reveal a method of correcting the deaf set so that the distortion factor of the set will be very different for different types of deafness. For such cases it is expected that the simple method of combining these two factors which has been described here will not apply.

It will be seen from the curves of Fig. 4 that when one has 0 per cent hearing, no known aids will enable him to understand speech satisfactorily. When speech is amplified the energy of the vowel sounds is sufficient to cause annoyance and even pain before the volume of the consonant endings are sufficiently loud to be heard. It is by virtue of these endings that speech is interpreted, so although 0 per cent hearing, as used here, does not necessarily imply that the person cannot hear any sounds, it does mean that the auditory sense cannot be used to interpret speech even when aided by the best means known. Even with 20 per cent deafness it is very unlikely that a deaf set will give any satisfactory help, although if in such a case it happens that the ear distortion is very small the type "A" deaf set may give some aid.

This method of predicting the amount of aid received from using various types of deaf sets is admittedly only very approximate, but, nevertheless, it should be very useful. Our experience with a limited number of cases of deafness has shown that it agrees approximately with the observed results.

It is hoped that this preliminary discussion of so important a matter may stimulate sufficient interest to cause some workers in the otological field to take a serious interest in the problem so that in the near future we may be able to answer satisfactorily the questions so important to one suffering from loss of hearing, "What type of apparatus will aid my hearing and how much improvement should I expect by using such a device?"

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